# IMPEDANCE MEASUREMENT OF VACUUM CHAMBER COMPONENTS FOR THE ADVANCE PHOTON SOURCE (APS) UPGRADE*

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## *Abstract*

The proposed Advance Photon Source Upgrade (APS-U) employs a multi-bend achromat (MBA) lattice to increase the photon brightness by two to three orders of magnitude. One of the main design challenges of the upgrade is to minimize rf heating and collective instabilities associated with the impedance of small-aperture vacuum components. As part of this effort, my research focuses on impedance measurement and simulation of various MBA vacuum components. Here, we present the summary of the impedance contributions for the APS-U and describe our planned impedance measurement technique, including some measurement results for the non-evaporative getter (NEG)-coated copper chamber and simulation results for other critical components using a novel Goubau line (G-line) set up.

## INTRODUCTION

The stable operation of advanced accelerator facilities requires careful examination and control of the longitudinal and transverse impedances/wakefields that can drive different types of collective beam instabilities [1,2]. These instabilities are caused by the interaction of the beam with its surroundings. The strength of the interaction to a particular vacuum component is characterized by its coupling impedance, which ultimately determines the performance of an advanced accelerator. Though the theory of coupling impedance is well developed and some sophisticated simulation codes to calculate the impedance of a particular component are available, rf measurements continue to provide an important verification tool. As a way to complement, validate, and cross-check electromagnetic simulations, we plan to measure the longitudinal coupling impedance of some critical APS-U vacuum components including the BPM-bellows assembly, the in-line photon absorbers, the gate valve liners, the RF-sealed flanges, and potentially the injection/extraction kickers.

Predicting collective effects in a storage ring depends upon both the transverse and longitudinal impedance over a wide range in frequency. We summarize the longitudinal sources of impedance in Table 1 using the summed $\Im(Z_{\|}/n)$ and loss factor $\kappa_{\text{loss}}$ for a 50 ps bunch for each component; the former characterizes the relative contribution to the microwave instability, while the latter quantifies the expected rf-heating.

## EXPERIMENTAL MEASUREMENTS

In this section we present impedance measurement results of the NEG-coated copper chamber for the APS-U, showing that the planned 1.5 micron coating contributes negligibly to the impedance up to 30 GHz. Next, we briefly present how we will implement the Gobau-line method to measure the impedance of a variety of other vacuum components, and summarize our future experimental plans.

### *Measurements of NEG-coated Copper*

There has been significant progress recently to measure the resistivity of NEG [3]. Nevertheless, there is some disagreement over the extent to which micron-thin coatings of NEG will contribute to collective effects in storage rings. For this reason, we decided to try and experimentally determine the impedance of a sample NEG-coated copper chamber that has the same geometry as that planned for the FODO section of the APS-U MBA. The FODO section has strong bending magnets which produce high synchrotron radiation loads and the NEG coated chambers primarily reduce the photon simulated desorption while also providing distributed pumping. We used the traditional coaxial-wire technique [4] to evaluate the impedance of the NEG-coated copper chamber. The goal of this experiment was to try and verify that the planned 1.5 micron thick coating is mostly invisible to the beam over a wide spectral range up to 30 GHz. The experimental set up consists of a pure copper pipe and the NEG coated pipe respectively connected to the HP8510C network analyzer, with the help of 3.5 mm coaxial cables which provides 50 Ω matching network at both ends of the chamber and is shown in Fig. 1.

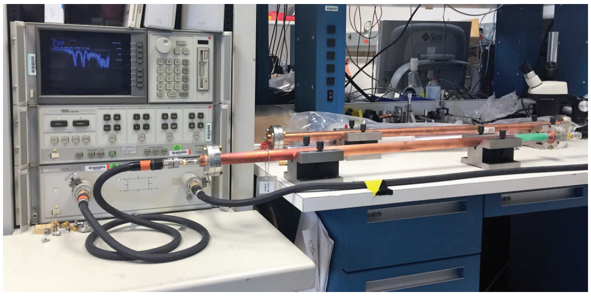

Figure 1: Bench measurement set up to calculate the impedance of the NEG coated copper chamber at Argonne National Labrotary.

To study the effect of NEG coating we first scanned the forward transmission coefficient, also called $S_{21}$ parameter, over its full range 0-50 GHz, and then chose some specific bands where repetitive measurements could be recorded

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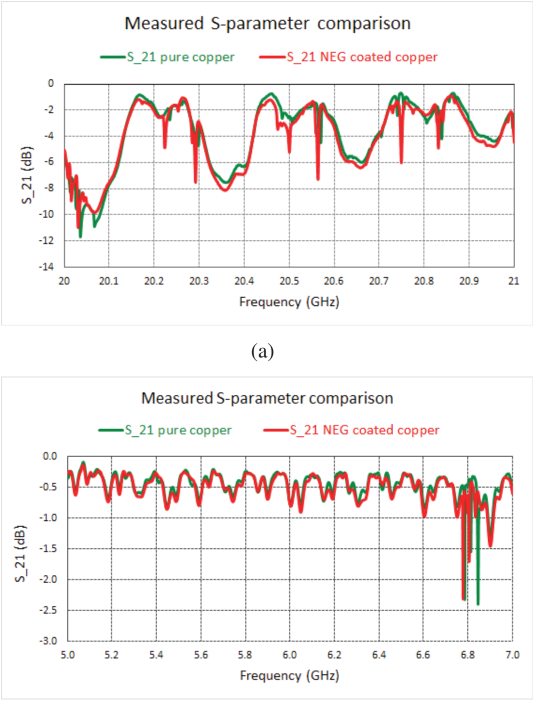
Table 1: Summary of Impedance Contributions for the APS-U

| **Impedance source** | **Number** | $\Im Z_{\parallel}/n(\Omega)$ | $\kappa_{loss}(\sigma_t = 50$ **ps) (V/pC)** |
|---|---|---|---|
| BPM-bellows | 560 | 0.048 | 0.090 |
| In-line absorber | 760 | 0.060 | 0.045 |
| Gate valve | 160 | 0.020 | 0.002 |
| Flange | 1880 | 0.011 | $< 10^{-3}$ |
| ID transition | 40 | 0.0018 | $< 10^{-3}$ |
| Crotch absorber | 80 | 0.0070 | 0.002 |
| Pumping cross. | 200 | 0.0015 | $< 10^{-3}$ |
| Injection/extraction kickers | 8 | 0.0075 | 0.94 |
| Small-gap ID BPM | 30 | 0.0013 | 0.008 |
| 352 MHz rf-cavity | 10 | 0.001 | 3.8 |
| Rf transitions | 3 | 0.018 | 0.84 |
| Resistive wall | NA | NA | 2.18 |
| **Total** | NA | 0.18 | 7.9 |

with good accuracy. We picked three bands: 5-7 GHz, 20-21 GHz, and 28-29 GHz, and measured the forward transmission coefficient of the one meter long pure copper pipe, and then sent it out for the NEG coating. We repeated the measurement again after NEG coating using the same frequency bands. Measured results for the pure copper chamber and NEG coated copper chamber are shown in Fig. 2, where the green curve represents pure copper pipe and the red curve indicates the NEG coated copper chamber.



(a)

(b)

Figure 2: Measured $S_{21}$ parameter for the one meter long pure copper pipe (green), and for the NEG coated copper pipe (red) in the frequency range: (a) 5-7 GHz and (b) 20-21 GHz.

Measured plots show that NEG coating has negligible impact on impedance up to 21 GHz as predicted by simulation. Above this frequency, we did not observe the clear difference between copper pipe and NEG coated pipe as predicted by simulation. Rather, the NEG coated chamber shows slightly higher transmission at higher frequencies, which is unexplained but may not be significant. Additional measurements are planned to disclose this unusual behavior of NEG at high frequency.

### *Goubau Line for Future Impedance Measurements*

The traditional coaxial cable method for impedance measurement has several limitations; one of the main constraints is the relatively large diameter of the central conductor inserted inside the device under test (DUT) to resemble the beam profile, which introduces large uncertainties in the centroid location of the conductor. On the other hand, using a thin central conductor necessitates an impedance matching section that complicates the bench testing set-up.

We plan to use a novel technique based on technique that uses a Goubau line (G-line) to evaluate the impedance of the remaining critical APS-U vacuum components. The G-line is a dielectric coated single wire transmission line based on the principle of Sommerfeld-like surface waves [5]. A surface wave propagates in the interface between the central conductor and thin dielectric material coated on its surface. Surface-wave based transmission line permits RF energy to be launched on the wire, travel though a beamline component, and then finally be absorbed in a load. A single wire can easily be constructed up to couple of hundred microns, which more accurately approximates the electron beam physical profile [6]. Electromagnetic fields for this single wire transmission line are excited by two cones, also called launchers or horns, that serve to match the impedance from 50 Ω to that of the single conductor. A CAD model of the G-line system with a BPM-bellows assembly is shown in Fig. 3. The electromagnetic fields around the G-line are represented by the Hankel function of first order [4] which implies that the radial electric field decreases linearly in the vicinity of the wire and decays exponentially after that. Hence, with an appropriate choice of wire and dielectric properties, the field can be designed to simulate the effect of an electron beam over the region of the device under test. Easier set up, broad band data acquisition and relatively more accurate impedance matching of the circuit makes the G-line superior to the traditional stretched wire method.

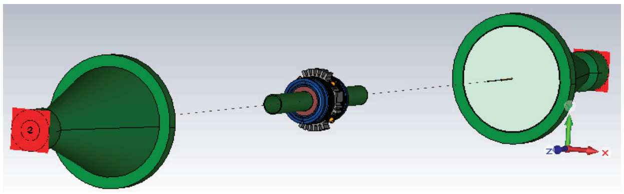
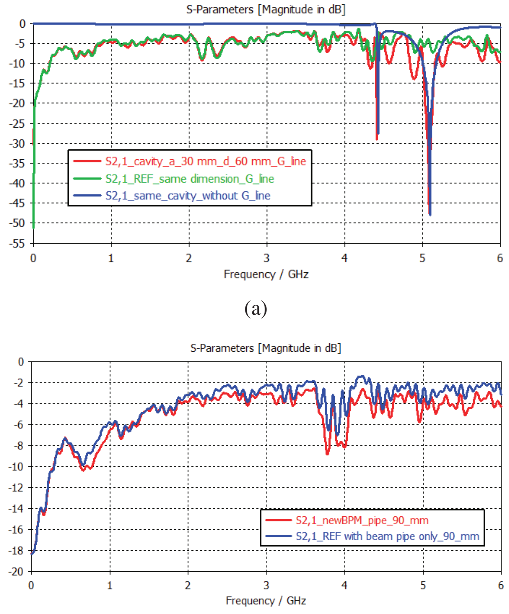


Figure 3: CAD model of the G-line set up with a BPM-bellows assembly in the center.

To test the effectiveness of the G-line system, we simulated $S_{21}$ parameter of a pill box type copper cavity, having inner radius $a = 30$ mm and width $d = 60$ mm with a 22 mm diameter beam pipe attached to its both side walls, in the G-line system and compare the result for the same cavity without G-line using CST Microwave Studio [7]. The simulation plots for these comparisons are shown in Fig. 4(a), where the red and the blue curves represent the measured G-line response to the cavity and the reference (REF) structure respectively, while the dark blue curve indicates the same cavity response in the transient solver without G-line. The comparison depicts that not only the higher order resonance peaks lie exactly on the same position, but also reveals mostly the same amplitude of the resonance peaks. In addition, we can see that subtraction of the reference signal from the cavity in the G-line system reproduces the same curve without G-line system. This test is quite encouraging and additional work is on going to simulate for other APS-U components. As an example, we present our preliminary simulation results for the BPM-bellows assembly using the novel G-line system in Fig. 4(b), where the red curve represents the BPM-bellows response, and the dark blue curve represents its corresponding reference structure. Simulation plots show the clear difference between the forward transmission coefficient, from which the impedance of the BPM-bellows assembly can be evaluated.

## CONCLUSION AND FUTURE WORKS

The measured results show that the effect of impedance due to the 1.5 micron thick NEG coating on copper is mostly negligible up to 21 GHz, as predicted by simulations. In 28-29 GHz range, we did not observe the linear dependence of impedance on frequency predicted by simulation. Rather, the NEG-coated chamber shows slightly higher ($\leq$ 1 dB) transmission at higher frequencies, which is unexplained but may not be significant. Additional measurements are planned.



(a)

(b)

Figure 4: (a) Simulated $S_{21}$ parameters for a pill box type cavity in G-line (red), corresponding reference pipe in G-line (light green), and the same cavity without G-line (dark blue). (b) Simulated $S_{21}$ parameters for the BPM-bellows assembly (red), and its reference (dark blue) in the G-line.

Our next plan is to measure the geometric impedance of other APS-U vacuum components including the BPM-bellows assembly, rf-flanges, gate valve liner, and potentially the injection/extraction kicker magnet using novel G-line technique. A G-line based impedance stand has been built and is being assembled to perform these measurements. Preliminary simulation results for a pill-box type cavity and the MBA BPM-bellows assembly using this technique depicted encouraging results.

## ACKNOWLEDGMENT

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